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FORTY KILOVOLT MEGAWATT AVERAGE POWER THYRATRON (MAPS 40), (U)

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Research and Development Technical Report
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FORTY KILOVOLT MEGAWATT AVERAGE POWER THYRATRON (MAPS 40)

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The purpose of this 12 month program is to develop a 40 kilovolt-megawatt average power thyratron. Electrical objectives are to switch 40 kiloamperes at 40 kilovolts with a pulse width of 10 microseconds and a repetition rate of 125 hertz. A thyratron design to meet these objectives has been evolved. The design has been evaluated for thermal and mechanical characteristics. Two preliminary devices have been fabricated and tested at ECOM at 70% of the average power level objectives.

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1. INTRODUCTION

The purpose of this interim technical report is to provide a succinct summary of the work performed on behalf of the U.S. Army Electronics Command, Fort Monmouth, New Jersey, on the development of a 40-Kilovolt, Megawatt Average Power Thyratron (MAPS-40) under Contract No. DAAB07-76-C-1352, between the commencement date of May 20, 1976 and December 31, 1976. Principal performance characteristics for the required tube are listed in Table 1.

Much, as originally envisioned, of the effort during this early formative stage of the program was absorbed in the following vital, ground-level, tasks:

1. Confirmation, refinement, and freezing of design parameters presented in the original EG&G proposal dated 12/1/75.

2. Part procurement which included several, highly specialized, long-lead items.

3. Assessment of vital operating factors through the evaluation of preliminary experimental thyratron vehicles.

4. Solution of intricate technological problems related to the necessarily massive structure of the ultimate tube.

5. Assembly and evaluation of two developmental sample tubes constructed on the basis of initial design considerations.

It will be appreciated from the above that accomplishment in terms of concrete end-objectives was, of necessity, meager during this period. The bulk of fundamental, often times exacting, groundwork for later development was nonetheless generated at this time.

Table 1. Major Specification Objectives for MAPS-40 Thyratron.

Parameter (Units)	Rating	Operation (1)	Operation (2)
epy (kV)	40	44	44
ib (ka)	40	44	11
tp (μs)	--	10	20
prr (Hz)	500	125	250
Ib (A dc)	50	50	50
Ip (kA ac)	1.4	1.48	0.74
Pb (10^9 va/s)	400	242	121
dik/dt (ka/μs)	20	20	20
tad (μs)	--	0.2	0.2
Δtad (μs)	--	0.1	0.1
tj (μs)	0.02	--	--
Ef=Eres (Vac)	15 ± 1.5	--	--
If (A ac)	70	--	--
Ires (A ac)	40	--	--
tk (sec)	900	--	--
Life (pulses)	--	5×10^6	5×10^6
egy to be between 1500 and 4000 volts.			

Notes for Table 1:

The conditions listed above describe the on-cycle or burst conditions. The 300-second off-periods in Operations (1) and (2) reduce the average conditions to:

Ib (A dc) = 5

Ip (A ac) = 442

Other conditions:

Standby	48 hours - heaters only
Reliability	25 pulses (max) - extra or missing pulses during life
Weight	25 lb (max)
Volume	0.5 cu ft (max)

2. DESIGN CONSIDERATIONS

Design goals for the subject development were defined in the Technical Guidelines entitled "40 Kilovolt-Megawatt Average Power Thyratron (MAPS-40)," and are summarized in Table 1.

Distinguishing features of the objective specifications were those addressing the attainment of the following extrapolated performance levels:

1. Operation at an epy level of 40 kilovolts.

2. Discharge into a one-half ohm load, equivalent to 40 kiloamperes of peak current.

3. An rms current of 1400 amperes.

4. Reliable switching under stress conditions imposed by an adiabatic mode of operation.

5. An average power of 1 megawatt.

The design of a hydrogen thyratron capable of meeting these objectives was reviewed in great detail and in the light of recent inputs derived from related MAPS thyratron programs. The principal design factors considered in this analysis are outlined below.

In the grid-anode region, particular attention was given to forward voltage hold-off by the introduction of a gradient grid and by the design of a cathode of minimal material migration, optimizing the form factor and the baffling of the control and gradient grid apertures, as well as their individual thicknesses, and filling the tube with deuterium.

The problem of current quenching was attacked on the strength of available experimental information. The latter indicated that a total grid aperture area of approximately 7-1/2 square inches would be necessary to circumvent the quenching problem. A direct consequence of this design decision was the development of an 8-inch diameter ceramic tube.

Inverse hold-off continued to be regarded as a serious problem, in face of the peak current levels involved. It was decided to seek relief in this direction by the introduction of a "virtual anode" approach.

Grid dissipation was considered in its multifarious aspects and in light of the adiabatic mode of operation. Adequate thermal mass and conductivity were incorporated in the design to offset potential instabilities. Refractory metal was applied to areas of maximum thermal stress. Extensive use was made of molybdenum to resist and attenuate the more damaging end-products of arcing.

Design of the auxiliary grid and cathode baffle adhered to standard thyratron practice. The hydrogen reservoir was studied from the standpoints of adequate storage capacity and response time as compared to the enormous amount of gas clean-up anticipated during the long "on" cycles of operation.

While, clearly, a number of areas of mild to serious uncertainty existed at the time of tube design, no physical limitation of a magnitude which might preclude the feasibility of achieving the specified performance became evident in the course of the foregoing analysis.

Cathode design considerations were especially intricate in view of the severe stresses imposed by the burst mode and high rms current conditions of operation. Cathode surface emissivity and utilization were analyzed conservatively. Careful attention was paid to the problem of adequately supporting and current feeding the vane structure. The thermal properties of the structure were examined under full operating conditions in order to prevent the occurrence of potential thermal vane-tip runaway effects.

3. PRELIMINARY DEVELOPMENT

To conserve valuable developmental effort, and simultaneously acquire vital information concerning prime areas of functional uncertainty, it was decided to conduct preliminary development in thyratron vehicles wherein the parameters under investigation would be modified to simulate operating conditions pertaining to the final MAPS-40 tube.

With this in mind, developmental tubes Q-001 through Q-004 and a special HY-5, all of which have a cylindrical ceramic diameter of 4-1/2 inches, were constructed for the specific reasons outlined in Section 4.

It was similarly agreed to build the first few 8-inch diameter developmental MAPS-40 samples with a somewhat modified, existing 5,000 cm^2 cathode, judged adequate for the intended service, prior to the development of a new, totally compatible cathode structure, so as to identify, diagnose, and rectify unforeseen problems in the remaining portion of the device at an early stage.

Several other pertinent factors of lesser impact were also checked out, with the help of existing thyratrons, at the Salem laboratory during this period.

4. TUBE CONSTRUCTION

The following developmental samples were constructed during the interval reported:

<u>Q-001</u>

Design Parameters: A 4-1/2-inch diameter experimental triode, having a normal anode.

Purpose: To acquire pertinent current quenching data.

<u>Q-002</u>

Design Parameters: A triode similar to Q-001, but incorporating a virtual anode.

Purpose: To assess current quenching behavior in the presence of a virtual anode.

<u>Q-003</u>

Design Parameters: A tube similar to Q-002, containing a thick, gradient grid of the "box" type (grid thickness = 3/4 inch).

Purpose: To evaluate the influence of a thick grid on triggering and forward hold-off voltage, in the presence of a virtual anode.

Q-004

Design Parameters:	Built identically to Q-003, but had a regular anode in place of the virtual type.
Purpose:	To evaluate the effect of a thick grid on triggering and forward hold-off voltage, in the absence of a virtual anode.

Special HY-5

Design Parameters:	A special narrow-slotted close grid-anode spaced HY-5 thyratron sample.
Purpose:	To assess possible benefits in terms of recovery time.

MAPS-40, No. 001

Design Parameters:	The first 8-inch diameter, gradient grid, developmental MAPS-40 model, incorporating a virtual anode, is shown in the layout drawing of Figure 1.
Purpose:	To test initial MAPS-40 thyratron design assumptions.

MAPS-40, No. 002

Design Parameters:	The second 8-inch diameter tube, similar in all respects to No. 001, but incorporating an anode of regular design, as shown in the cross sectional drawing of Figure 2.
Purpose:	Further testing of initial MAPS-40 thyratron design assumptions.

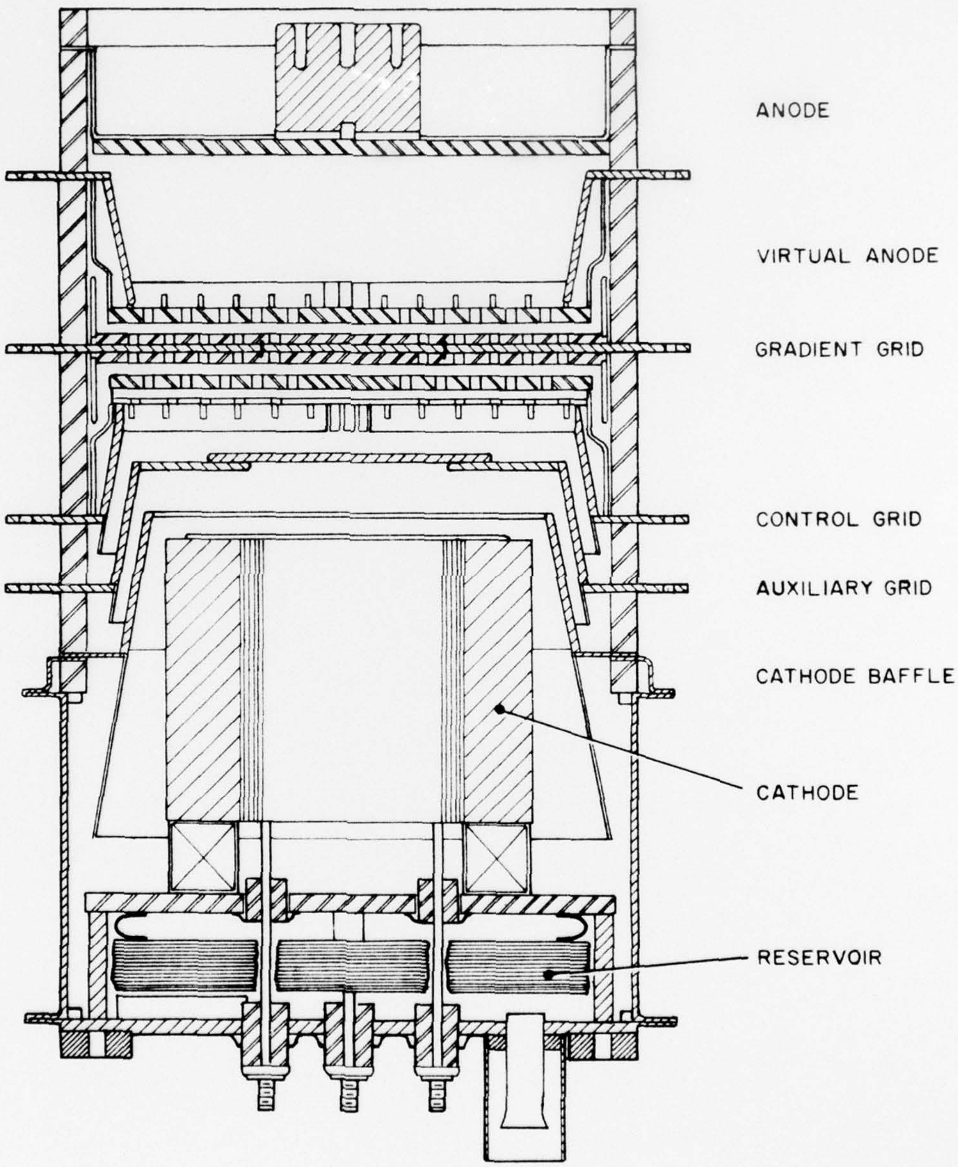

Figure 1. MAPS-40 No. 001.

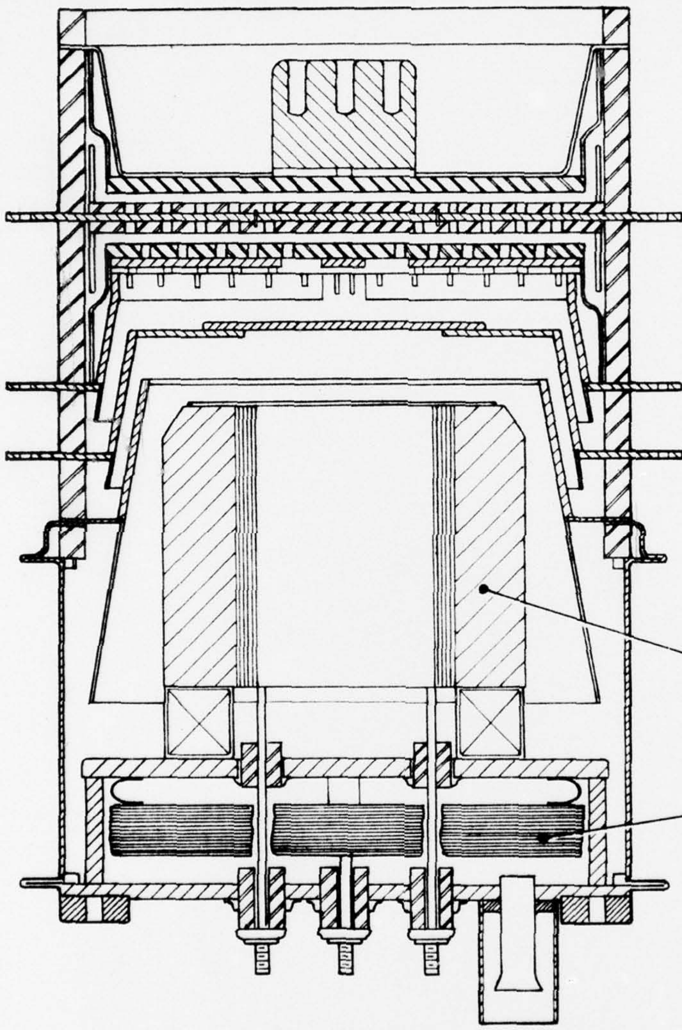

Figure 2. MAPS-40 No. 002.

Some major design features, common to both MAPS-40 developmental samples, were:

1) A single "box type" of gradient grid, giving two hold-off spaces at 20 kV each.

2) Wall shields for both high voltage spaces, attached to the gradient grid, giving a symmetric high voltage structure.

3) Molybdenum plates of various thicknesses used for the anode, gradient grid, grid, grid baffle, and cathode baffle. Moly bars were used to join the gradient grid halves together and to join the grid baffle to the grid. Extensive use of molybdenum gave both high thermal conductivity and dimensional stability under conditions of high transient power input.

4) Various elements of the tube were supported by a nesting set of conical sections, made of copper for maximum thermal conductivity.

5) Ceramic seals were butt seals, with nickel-iron alloys at the cathode and extreme anode ends, and with 1/16 inch copper at the grid and baffle element seals. This method was used to provide minimum height and high thermal conductivity.

6) The cathode was mounted on a massive copper sole plate, thermally connected to the mounting ring by copper bars. This structure was introduced to provide thermal isolation for the reservoirs against surge heating by the cathode during "on" cycles.

7) A large cathode, nearly 5,000 cm^2 surface area, originally designed for the MAPS-70 thyratron, was inserted after minor structural modifications within the 8-inch diameter envelope.

In addition, good progress was made (1) in the construction of a unipotential virtual anode, (2) in the design of a reservoir heater assembly of greatly improved reliability, and (3) in the early stages of development of a new, more compact MAPS-40 cathode of enhanced mechanical, utilization, and efficiency characteristics.

5. TUBE EVALUATION

Thyratron samples built during this period were partially or totally evaluated with the following results:

Q-001

The tube was tested at ECOM in a portion of the MAPS-40 experimental set-up at a pulse width of 20 microseconds. It exhibited current quenching at 3 ka peak, which translates into 9 ka per square inch, and is in reasonable agreement with extrapolations derived from smaller hydrogen thyratrons, and from large cylindrical discharge studies.

Q-002

The virtual anode introduced into this sample was intended to provide hydrogen storage in the grid-anode space and, thereby, improve current quenching behavior. It was also felt that because of ionization in the virtual anode cavity during the main pulse, the tube might perform as its own inverse clipper.

In actual fact, the tube proved generally much less stable than Q-001 with the onset of quenching appearing as low as 1.3 ka at pulse widths of 20 microseconds, increasing to 1.8 ka at 10 microseconds. In addition, it displayed sustained poor forward voltage hold-off and, while it provided some inverse clipping, it would not operate into a high inverse condition.

Q-003

This tube was equipped with a virtual anode to further explore the concept. It also incorporated a 3/4-inch thick gradient grid, of the box type, needed to provide high thermal capacity and conductivity in the MAPS-40 thyratron.

The triggering properties of the tube were found to be good, with only a small increase in delay time over that of a corresponding triode. Jitter and delay drift were unaffected. Use of a thick gradient grid was found to be non-restrictive insofar as these electrical parameters are concerned.

Forward and inverse voltage hold-off behavior, however, was very poor. This may be attributable to the use of a virtual anode structure. More extensive testing of the switch is believed necessary in order to correctly identify the source(s) of substandard performance.

Q-004

This tube was constructed to assess the effects of a 3/4-inch-thick gradient grid in the presence of a regular anode.

Results indicate that the influence of the thick grid on anode delay time, delay time drift, and jitter was minor. Also the forward hold-off voltage was far superior to that of tube Q-003, although still not quite up to expectations.

Further testing of this tube seems highly desirable.

Special HY-5

This tube was built with narrower grid slots (but unchanged total grid slot area) and shorter grid-anode spacing, considered to be of some advantage to recovery time.

Following considerable aging, the switch was operated up to 50 kV and at an average current in excess of 5 amperes. This was well-above-average performance for an HY-5 thyratron. It was not clear, however, whether any substantial gain had been made with regard to recovery time.

MAPS-40, No. 001

At Fort Monmouth, the tube was operated at heater and reservoir voltages of 24 and 10.5 volts, respectively. The auxiliary grid was tied to the cathode through a 660-ohm resistor, while the virtual anode incorporated in this tube was strapped directly to the anode section. The gradient grid was tied down by means of 20-megohm dividing resistors. The test circuit contained no inverse clipper and no thyrites were used in either the auxiliary or control grid leads.

Initially, the tube was operated into a 1-ohm line and, following gradual aging, it reached low duty operation at 40 kV. It was subsequently connected to a one-half ohm line and gradually brought up in voltage. The tube exhibited signs of stress in this condition. There were numerous kick-outs, arising from instances of self-firing following burst mode operation, and a considerable amount of inverse arcing. The tube reached a high point of Ebb = 15 kV, and an average current of 25A at 82 pps where, after another kick-out, it showed great reluctance to run at high epy. Subsequent cold hold-off voltage tests confirmed the fact that the tube had developed an air leak. At this juncture, it was returned to the Salem laboratory for further examination.

The tube was dissected and a complete examination of its internal electrode structure carried out. The cathode was found to be generally in good condition and its vane tips showed no sign of abnormal heating. The cathode shield bore marks of repetitive arcing. Except for some minor ion bombardment marks on the gradient grid, the grids and anode were in excellent condition. Some electrode eccentricity was noted for correction in future tubes.

The only destructive evidence appeared on the stainless auxiliary and control grid shield extensions. Here, severe arcing caused extensive meltdown around the edge of the stainless steel rings.

MAPS-40, No. 002

At ECOM, the tube was operated at heater and reservoir voltages of 24 and 10.5 volts, respectively. The auxiliary grid was again tied down to the cathode through a 660-ohm resistor and the gradient grid by means of 20-megohm dividing resistors. Thyrites were used in the auxiliary and control grid circuits.

The tube aged up to 40 kV with a 1-ohm line, without undue difficulty. However, upon turning over to a one-half ohm line, problems began to appear at 22 kV. A severe kickout situation developed and the tube exhibited heavy clipping. After considerable aging and trimming of the cathode and reservoir heater voltages, the tube was able to reach a peak operating level of 35 kV, 35 kA, with corresponding average current and power levels of 40 amps and 0.7 MW.

Its performance deteriorated beyond this point until it became inoperable, due to high electrical leakage which developed between the control and auxiliary grids as well as between the auxiliary grid and the cathode. Attempts to clean up the contamination responsible for this low resistance proved ineffective and ultimately led to opening up the tube to air.

The tube was then dissected and analyzed in great detail. Just as in serial No. 001, the grids and anode were in good condition. Except for the hastelloy cover, which was somewhat warped and bore arcing pot marks, the emissive surface of the cathode was in excellent condition and the vane tips exhibited only normal signs of minor overheating. The molybdenum gradient grid shield showed signs of arcing over a one-inch portion of its circumference. Again, the auxiliary and control grid shield extensions were the only areas where severe arcing and meltdown occurred; in this case, over most of the circumference of each stainless steel ring.

6. SIGNIFICANT ATTAINMENTS

Although severely hampered by long-lead material procurement delays and a series of technological start-up problems, arising from the necessarily massive structural design of the MAPS-40 thyratron, the developmental effort expended on the program attained some significant technical milestones. These are summarized in Table 2 for purposes of comparison and convenience.

Verification of preliminary assumptions in the early developmental vehicles, Q-001 through Q-004 and the special HY-5, was prerequisite to the final design of the MAPS-40 tube. These inputs were obtained in an orderly and timely fashion.

Also, despite the early catastrophic failure of developmental MAPS-40 samples No. 001 and No. 002, the following valuable inputs were obtained:

1) No fundamental design restriction was encountered in either tube to the maximum level of operation possible in each case.

2) The thermal design of the grids and anode displayed great promise.

3) The cathode showed no signs of stress.

4) Partial electrical evaluation, followed by meticulous dissection of the tubes, led to early identification of critical weaknesses in the area of the auxiliary and control grid shields for immediate corrective action in subsequent tubes.

Table 2. Significant Attainments.

Developmental Tube Number	Information Gained
Q-001	- Level of quenching current verified. Need for 8-inch diameter tube confirmed.
Q-002 and Q-003	- Introduction of a virtual anode, of the configuration envisioned at the outset, would be quite detrimental.
Q-004	- Presence of a thick gradient grid exerts no adverse influence of any consequence on anode delay time, delay time drift, or jitter.
Special HY-5	- Narrower grid slots and shorter grid-anode spacing may exert some beneficial influence on forward voltage hold-off and recovery time.
	- Results are inconclusive thus far.
MAPS-40 No. 001 and No. 002	- Numerous critical assembly and exhaust problems associated with the massive tube structure were encountered and resolved.
	- Partial specification performance was demonstrated. Inherent strengths and weaknesses of the electrode structure were revealed.
	- No fundamental design restrictions were encountered. Modifications for future enhancement were suggested by experimental evidence. The need for controlled and methodical aging has been underlined.

7. PROGRAM STATUS SUMMARY

At approximately half-way in the study, the MAPS-40 development program has reached several crucial, albeit supportive, goals, enumerated in Section 3, in the painstaking preparatory stage which usually precedes state-of-the-art advances of real consequence.

Considerable evidence, furnished throughout this report, suggests that the basic design of the switch is founded on sound assumptions and on firm engineering principles. While more difficulties may be in store for the second half of the project, successful prototype hardware can confidently be expected to emerge in the forthcoming year.

A brief description of 1977 program objectives is given in Section 8. Areas of further research and development, as well as engineering refinement considered essential to the achievement of the specified switch performance, are also outlined.

8. MAPS-40 RESEARCH AND DEVELOPMENT PROGRAM OBJECTIVES FOR 1977

8.1 TUBE CONSTRUCTION

Construction of the following three developmental samples for specific evaluation and/or life test:

1) One containing a unipotential virtual anode with baffled apertures and a small cavity.

2) One incorporating an advanced cathode design tailored to the needs of the MAPS-40 adiabatic mode of operation.

3) One whose design parameters will be based on the most promising inputs obtained from related test findings.

8.2 FORWARD/INVERSE HOLD-OFF EVALUATION

Evaluation of factors affecting these parameters will be carried out. In this context, ceramic wall phenomena, the effect of cathode decomposition products, the influence of shields, and the effect of external ceramic surface conditions will be investigated.

8.3 EVALUATION OF GRID PARAMETERS

Thermal properties will be reassessed by means of further calculation and/or pertinent simulation.

Measurement of actual grid dissipation will be performed by direct calorimetry on a suitable vehicle.

Significant grid design refinements are expected to emerge from the evaluations.

8.4 CATHODE DESIGN

State-of-the-art aspect ratio design criteria, currently applied to the emissive vane structure, will be re-appraised in an effort to optimize the thermomechanical efficiency of the existing cathode design.

Different processing techniques will be tried-out at the same time, in order to arrive at an optimum conditioning of the cathode emissive properties.

A cathode of entirely new design will be constructed and evaluated. Environmental testing of both the existing and the new cathode structures will be carried out.

8.5 RESERVOIR DESIGN

In addition to incorporating design changes aimed at improved reservoir heater reliability, experiments are planned to test such parameters as reservoir capacity, response time, and transient/long-term clean-up which are vital to the unique mode of operation of the MAPS-40 switch.

8.6 ASSESSMENT OF ADIABATIC MODE PERFORMANCE

A concerted effort will be made to assess the special effects of the adiabatic mode of operation on various design parameters of the tube under running conditions and, where feasible, compare them with assumptions made at the outset of the program.

8.7 SUMMARY

The sum-total of inputs derived from the foregoing evaluations will allow the design of the MAPS-40 hydrogen thyratron switch to attain an advanced state of development.

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